CHAPTER 5
System and Component

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CHAPTER 5
System and Component

5.1 General Design Criteria.

5.1.1 Machinery Component Criteria. All components of lock gate operating equipment should be designed for the maximum normal full load torque of the electric motor, or the maximum effective hydraulic actuator pressure, with a minimum factor of safety of five (5.0) based on the ultimate tensile strength of the material. All components should be designed for a unit stress not to exceed 75 percent of the yield strength of the material, using the locked rotor torque rating of the electric motor, or the maximum hydraulic actuator pressure available through the control system. A fracture mechanics/fatigue analysis should also be performed which may place a lower limit on the percentage of yield strength that should be used. Components, which may fail in buckling compression, should be designed for a minimum factor of safety of three (3.0), using the Euler or J.B. Johnson formulas, as appropriate. These criteria determine the maximum allowable stresses for all components. Components used as fuses, such as some shear bolts, keys, torque-limiting couplings, etc. will not be designed to this criteria.

5.1.2 Standard Manufactured Products. All standard manufactured products should be selected based upon the manufacturer's published catalog ratings, or actual data procured by correspondence with all known major manufacturers of that type of component. The intent is to provide for full, open competition for standard manufactured items, while permitting the designer to use available data to provide a fully functional design. Plans and specifications should be performed in a manner that defines a range of performance obtainable by a majority of the manufacturers.

5.1.3 Bearings.

5.1.3.1 Antifriction Bearings. Ball, roller, tapered roller and spherical roller bearings should be selected in accord with the manufacturer's published catalog ratings of the group, type and size required. Bearing life should be designed as a B-10 life of 10,000 hours with a maximum design load of 75 percent of the maximum bearing Basic Dynamic Capacity (BDC) rating. Bearings, which remain static for extended periods, should be designed with greater safety factors, using the Basic Static Capacity (BSC) rating. Proper seals and lubricant design are essential to adequate performance. Only one fixed mount bearing should be used on shafts with multi-bearing installations to permit thermal expansion in the axial direction. Manufacturers should be consulted for typical axial capacities of the bearings.

5.1.3.2 Plain Bearings. Plain bearings, also identified as sleeve bearings, bushings, etc., should be designed for a maximum normal bearing pressure of 6.9 MPa, (1000 psi) except for bearings operating below five (5) revolutions per minute. Under special, slow speed, uniform load conditions, the bearing pressure may be designed for up to 27.6 MPa. (4000 psi). Bearing materials should be specified as Alloy C90500, for most slow to moderate speed applications, in accord with ASTM B271, ASTM B505, or ASTM B584. Special materials, or pressure designs, should be coordinated with several manufacturers to insure adequate competition is available.

The length to diameter ratio (L/D) should be designed close to unity (1.0), considering the bearing pressure required, in order to minimize wear and misalignment. Some consideration should be given to spherical plain bearings for such things as tainter gate trunnions, bellcranks, struts and other partial rotation, slow motion joints. Spherical bearings minimize wear between pins and bushings by accommodating modest misalignment.

5.1.3.3 Pillow Blocks. Pillow blocks should be cast iron, cast steel, or fabricated from forged steel. Pillow blocks should be designed to provide full radial and axial capacity in all directions. Mounting bolts, nuts, etc. should be rated for the full BSC in all directions, including upward through the cap. Slotted mounting holes may be used for the base, as required, but dowel pins or keeper bars should be permanently installed after final alignment and testing. Only one fixed mount pillow block should be used on shafts with multiple pillow block installations to permit thermal expansion in the axial direction.

5.1.3.4 Pintle Bushing.

5.1.3.4.1 Pintle bushings for lock gates traditionally have been grease lubricated aluminum bronze. The aluminum bronze alloy used is typically C95400 meeting the requirements of ASTM B148 or ASTM B271. Plate B-51 provides recommended grease groove and seal details. The aluminum bronze bushing is press-fit into the pintle socket and secured by bolting to the socket. The bearing surface should be finished truly hemispherical and the pintle balls fitted to the bushings by scraping or lapped until uniform contact is attained over the entire bearing surface. This can be determined by testing with carbon paper or similar media transfer technique. The pintle and bushing need to be match-marked. Show finish surfaces on the drawings in accordance with ASME B46.1. Determining compliance with surface requirements is typically done by sense of feel and visual inspection of the work and comparing it to the Roughness Comparison Specimens of ASME B46.1. Paragraph 2.1.7 and Plates B-53 and B-54 provides additional information. Grease lubricated bronze continues to work well but environmental issues, created by pumping grease to the pintle bushing, has caused us to also consider using self-lubricated pintle bushings.

5.1.3.4.2 Self-lubricated bearing material, also known as composites, has been produced for many years, but the Corps has been reluctant to recommend its use for pintle bushings since some Corps projects have experienced composite bearing failures. The Construction Engineering Research Lab (CERL) has conducted a number of research projects to study the performance of self-lubricating materials, first for hydropower application and more recently for navigation lock and dam application. Some materials and arrangements have worked better than others. The composite is typically fitted in a bronze housing through interference fit and fasteners. The pintle is typically manufactured of cast steel with bearing surfaces of stainless steel deposited in weld passes to a thickness of not less than 4.8 mm (0.1875 inch) and machined to the required shape. When considering the use of self-lubricated pintle bushing, the reports produced by CERL should be reviewed, especially draft report titled: Field Evaluation of Self-Lubricated Mechanical Components for Civil Works Navigation Structures. Selecting the correct type of self-lubricated bushing, specifying the proper design criteria, i.e., composite thickness, surface finish, interference fit, clearance fit, etc., for each particular application is critical to ensure a successful installation. The draft CERL report identifies Corps lock and dam projects that have used self-lubricated pintle bushings. Most installations are relatively recent and long term results are still unknown. Designers should contact the districts identified in the CERL report to get an update on the information provided in the report. The better performing bearing manufacturers identified in the report should be consulted about recommendations to select the best bushing arrangement and specify design criteria to best suit each application. Successful use of composites for pintle bushings is still evolving and districts considering its use should proceed with caution.

5.1.4 Brakes. Holding brakes should be the shoe type, spring set, with DC magnet operated release. Brakes should have a minimum continuous duty torque rating of 150 percent of the maximum full load torque rating of the electric motor, or hydraulic actuator, as applied to the brake wheel. Fuses should not be used in the brake control circuit. AC-rectified brakes are acceptable. Brakes should be mounted in a watertight and dust-tight enclosure, with a heater, manual release devices, limit switches, indicators and electrical connections, as required by the operating environment. UFGS 16905A provides specification requirements for brakes.

5.1.5 Couplings. Flexible couplings should be the gear type. Couplings should be selected using the manufacturer's published rating. Couplings should have steel housings, with integral lips to contain the seals and retain the sleeves. Sleeves should be fastened such that they cannot slip or loosen. Couplings, which use snap rings to hold the sleeves, should not be permitted.

5.1.6 Efficiencies. The following operating efficiencies should be used as a design guide.

Silent Chain (including oil-retaining case)	97%
V-belts (including drive/driven sheaves)	90%
Spur Gear Reduction Unit (up to)	
1:1 to 16:1	88%
16:1 to 40:1	84%
40:1 to 150:1	78%
Helical, Herringbone or Planetary Reduction Unit	
Single Reduction	97%
Double Reduction	95%
Triple Reduction	90%
Quadruple Reduction & Worm Gear Reduction Unit	[1]
Spur Gear Set	97%
Bevel Gear Set	95%

[1]Certified starting and operating efficiencies should be obtained from manufacturers' data for the normal operating speeds. Special operating conditions, such as high or low ambient temperatures, or lubricant heaters, should be coordinated with the manufacturers' engineering department. The lowest efficiency obtained from a minimum of three standard manufacturers should be used.

Bearings	
Ball and Roller	98%
Bronze Plain Bearings (> 5 rpm)	95%
Bronze Plain Bearings (< 5 rpm)	93%

5.1.7 Force Control Limit Switches. Force control limit switches can be used to control overloads in multi-part reeved wire rope hoists. The device can be installed between the wire rope and the dead end anchorage of the reeving. High, and low, force control limits can be set with backup trip switches for each limit. A switch can be set for high loads, such as locked rotor torque upon seizing of a gate in its operating slot, while a second switch is set higher as an emergency backup device. A low load switch can be set for the load encountered in raising due to a seized sheave. Low load, at the end anchorage, would be indicative of an overload in the portion of the wire rope from the sheave nest to the drum. The main limit switches interrupt the control circuit, while the backup switches de-energize the hoist. The forces are determined by calculating the wire rope tension that would be produced by the maximum load used in the design of machinery components. Backup switches are typically set at approximately 900 kg (2,000 pounds) differential from the primary switch.

5.1.8 Torque Limiting Devices. Slip clutches can be used to protect gate operating mechanisms by limiting the maximum motor torque applied to them. Multi-plate slip type clutches with fiber type friction discs are recommended. They should be adjustable and use coil springs. Slip clutches are normally rated for 200 percent of the maximum calculated torque requirement, and should be adjusted to provide slightly more torque than required. However, the manufacturers recommendations should be considered for both sizing and adjustment. The torque capacity requirement is minimized if the clutch is located on the motor side of the speed reducer. Heat rejection capacity is not an important consideration as the device would not be expected to slip, except for very short periods. The designer should provide protection from the elements and oil or grease.

5.1.9 Open Spur Gears. Open gears should have spur teeth of the involute form, in compliance with applicable American Gear Manufacturers Association standards. Basic strength should be based upon the static load from the Lewis equation, as modified by the Barth Equation (design stress = Lewis stress x 600/(600 + pitch-line velocity-fpm). Large spur gears should be designed with forged steel rims in accord with ASTM A290, while the hubs and arms can be cast (ASTM A148), or fabricated from rolled steel plate. Large spur gears may be split radially, along two of the support arms, in order to permit more convenient handling and removal. The split line can be fastened by high strength bolting materials, designed for the maximum loads on the gear. Pinions should be fabricated from ASTM A291 forged steel. Pinion gear teeth should have a hardness of approximately 50 Brinell Hardness Number (BHN) greater than the driven gear teeth to equalize wear. Gears should not be overhung on shafts, including speed reducer shafts.

5.1.10 Round Link Chain. See Chapter 3 for a detailed description of round link chain design applications.

5.1.11 Shafts. Shafts should b designed for the machinery component criteria. The design criteria for all shafts should be the ASME Shafting Code equations with torsional and bending factors for heavy shock loading. The ASME Shafting Code requires additional stress reduction factors for keyways in the shaft. Stress concentration factors should be used, where applicable. Shafts should be fabricated from forged steel, such as ASTM A668. Shafts should be supported at locations required to minimize bending and axial movement yet allow for thermal expansion. The maximum bending moment deflection should be less than 0.83 mm/meter (0.01 in/ft) of length at the maximum rated load. Torsional shaft deflection should not exceed 0.26 degree/meter (0.08 degree/ft)of shaft length at the maximum rated load. Where spur gears are mounted on separate shafts, the relative slope of the shafts, at the centerline of the gear mesh, should not exceed one-third (1/3) of the gear backlash divided by the smallest gear face width. The typical backlash for spur gears is 0.03/DP to 0.05/DP, where DP is the diametral pitch.

5.1.12 Sheaves. Sheaves should be heat-treated cast steel, ductile iron, or manganese steel. Each sheave should have a groove and pitch diameter that corresponds to the recommended factors for the mating wire rope. The hubs should be fitted with plain bearings or roller bearings with appropriate lubrication fittings. The sheave flange, rim thickness, web thickness, angle of contact, and inside diameter of the hub dimensions should be in accord with the standard manufacturers' typical product for the appropriate size and construction of wire rope. The choice of a larger sheave diameter, for a given nominal wire rope size, improves fatigue life and reduces bending stress for the wire rope.

5.1.13 Speed Reducers. Speed reducers should be helical, herringbone, spiral bevel, or worm type in accord with the applicable AGMA standards. Speed reducers should be selected based upon the manufacturers' published ratings, including service factors, for the required operating conditions. Special shaft diameters, or lengths, are available from most major manufacturers, as required. All speed reducers should be equipped with anti-friction bearings. Overhung loads on speed reducer shafts should be discouraged, unless available space is severely limited by design circumstances. Speed reducer lubricants, for the bearings and the gear sets, should be chosen for operation in the existing ambient conditions. Where ambient conditions will exceed the normal lubricant recommendations for the type of speed reducer required, a thermostatically controlled unit heater, or heaters, should be provided in the reducer enclosure. Heating elements should have a maximum watt density of 1.5 watts per square cm (10 watts per square in.). Synthetic hydrocarbon lubricants may be an acceptable oil alternative, as approved by the speed reducer manufacturer for the normal loads and speeds encountered in service. A separate lubricating oil pumping system, which sprays all gears, and non-greased bearings, should be provided for speed reducers that operate infrequently, or will be placed in extended storage. Speed reducers should be specified with a lubricant thermometer, a level gauge, and a hygroscopic oil breather.

5.1.14 Wire Rope. Round wire rope is the typical product used for gate operating machinery. It is constructed to close dimensional tolerances with higher resistance to wear and mechanical damage than flat wire rope (woven wire rope with a rectangular cross-section). Wire rope selection criteria are provided in EM 1110-2-3200. Socket design is an important consideration to the implementation of wire rope installations. Epoxy products provide a viable alternative for the field installation of wire rope into sockets, but they require tighter tolerances on the openings in the sockets through which the wire rope must pass. Standard "zincing" can be very reliable, but does face galvanic corrosion problems in submerged or wet environments.

Any multiple wire rope system must have provisions for equalizing the tension in a group of wire ropes. A wire rope tensioning device should be specified, complete with a detailed tensioning procedure, to insure proper sharing of the load among the wire ropes.

5.1.15 Anchor Bolts. Anchor bolts should be designed for the maximum normal load, as well as the locked rotor torque criteria. Anchor bolt groupings should be de-rated for concrete shear cone overlaps. All anchor bolts should be detailed on the contract drawings with type of material, threads, head, depth of embedment and any special grouting or adjustment provisions. Anchor bolts, even those used only for shear conditions, should have hooks, bolt heads, "chairs" or body deformations designed to resist "pull-out" to the limits of the bolt tension rating. Anchor bolts should be installed with a weather-resistant template made from the actual device to be anchored. The specifications should have a detailed procedure for leveling the machinery on the anchor bolts, grouting, and pre-loading the bolts.

5.1.16 Fused Bolts. Several types of lock operating machinery include devices designed to fail at a pre-determined load to prevent overloading of other machinery components. The most successful method for performing this function is usually a "fused" bolt or bolts. Fused bolts can be designed to fail in tension or shear fairly accurately. Bolts fail most predictably in tension. A standard manufactured bolt, of a particular manufacturing run of bolts from the same material stock, can be load tested to improve the accuracy of a design. The designer, by calculating the approximate reduction in nominal diameter of the bolt required to fracture at a specific load, can test bolts machined to the reduced diameter to failure. Similar methods can be applied to shear connections made by bolts. The designer does, however, have to be very careful to insure that the maintenance personnel realize that replacement of the bolts with bolts of the same material and dimensions is critical. It is dangerous to replace these types of bolts with larger, stronger bolts, because the constant failure is inconvenient. Regular failure indicates another problem with the machine or the original design load criteria. Larger bolts could move the failure to a more critical design component. It's important to never use these devices on a gate that can fall causing damage to the structure. Fused bolts have been used successfully on many miter gate machine items, such as operating struts and cone brakes.

5.1.17 Keys, Pins and Splines. Keys, pins and splines are important connections in lock operating machinery designed to transmit power and motion to the gate. With rare exceptions, these items should be designed for the general design criteria, not for failure at or near design operating loads. Any item that, by its failure, can cause a gate or machine to "free-wheel" to impact with the concrete or steel structures, should not be allowed to be the weak link in the system.

5.1.18 Redundancy. Whenever possible and practicable, spillway gate operating equipment design should include redundant system or systems that will prevent failure of a gate to operate due a single component failure. For example, when a hoist motor fails on a multiple gated structure, a universal joint drive shaft assembly can be installed to cross connect between hoists to use an adjacent gate's drive machinery.

5.2 Hydraulic Fluid Power.

5.2.1 General Description and Application. Hydraulic fluid power systems generate, transmit, control and apply hydraulic fluid to devices which perform work. Power is generated by a pump mounted on a fluid reservoir. Pipe, tubing, hose and manifolds transmit the fluid to the output devices. Valves control the direction, pressure, and volume of the fluid flow. Actuators, such as hydraulic cylinders and hydraulic motors, are the typical output devices. Hydraulic fluid power output devices are often used to operate lock gates and spillway gates. UFGS 15010A, provides detailed assistance in the preparation of contract specifications of hydraulic fluid power systems.

5.2.2 Hydraulic Systems - General. Lock hydraulic systems are usually of a centralized power unit design, a local power unit design, a dedicated power unit design, or an integral power unit design. There are a number of variations of these systems, including adaptations for spillway gates. A typical centralized system has a single power unit location with piping and valves transmitting the fluid power to many different locations. A typical local power unit design places an individual power unit near the actuators to be operated at one corner of the lock. A typical dedicated power unit design has a single power unit adjacent to each actuator. An integral power unit design has a dedicated power unit attached directly to each actuator to form a single self-contained unit.

5.2.2.1 Centralized Power Unit. A typical centralized system has the power units located in a lock control building, usually on the second floor so it is above the flood of record. The building is usually located on the middle wall of a dual chamber lock, but can be on either wall of a single chamber lock. An extensive piping system connects the power unit to the miter gate and valve actuators. The piping system is installed in covered trenches or galleries on each wall and in crossovers to adjacent walls. A typical arrangement for dual chambers consists of a reservoir and three electric motor driven variable volume pumps. Two pumps are selected for service and one for backup on a monthly basis. The two variable volume service pumps operate in tandem and can supply multiple actuators on both chambers at same time. Proportional valves are normally used to provide variable speed control of the miter gates. A typical arrangement for a single chamber has two separate power units, with each dedicated to the actuators on one lock wall. The two power units are located adjacent to each other for cross-connection. Cross-connection of the main pressure, pilot pressure and return piping system allows the use of either system as back-up for the other during malfunctions. Under normal operating conditions each power unit will operate one miter gate or one culvert valve. If one pumping system is damaged, the remaining system can operate two miter gate leaves or two culvert valves at a reduced speed by pumping through the cross-connection system to the appropriate control system. The principal advantage of centralized systems are reduced first cost of power units, centralized maintenance, and smaller space requirements on the lock walls. The principal disadvantages are increased cost for piping, increased piping friction, cost for lock piping crossovers, increased vulnerability to leakage, reduced speed/load capacity during back-up operation or extremely cold weather conditions, and increased noise level when located in a control building.

5.2.2.2 Local Power Unit. A typical local system has a power unit located at each corner of the lock walls. Each power unit is used to operate the adjacent miter gate leaf and culvert valve. It is often deemed prudent to furnish each power unit with an extra main pressure pump, mounted on the same reservoir, to provide back-up power. The principal advantages of the local system are reduced first cost of piping, reduced piping friction, no cost for piping crossovers, reduced leakage, and lower noise levels in personnel areas. The principal disadvantages are increased first cost, decentralized maintenance, any special provisions for flood protection, and larger total space requirements.

5.2.2.3 Dedicated Power Unit. A typical dedicated system has a power unit located at each miter gate and each culvert valve. Each power unit is normally used to operate the adjacent miter gate leaf or culvert valve, but is cross-connected with the adjacent power unit to provide emergency back-up. The principal advantages of the dedicated system are reduced first cost of piping, reduced piping friction, no cost for piping crossovers, reduced leakage, full speed/load capability during back-up operation, and lower noise levels in personnel areas. The principal disadvantages are increased first cost, decentralized maintenance, any special provisions for flood protection, and larger total space requirements.

5.2.2.4 Integral Power Unit. An integral system combines a hydraulic power unit with a hydraulic cylinder to form a self-contained actuator that is completely sealed and submersible. Instead of directional valving, integral power units utilize a bi-rotational gear pump mounted inside a sealed reservoir and driven by a submersible electric motor attached to the reservoir. The speed and direction of the cylinder rod is controlled by a variable frequency drive, located in the motor control center, which controls the speed and direction of the electric motor. The principal advantages of an integral system are no first cost of piping, negligible piping friction, no cost for piping crossovers, minimal leakage, quiet operation, low maintenance, submersible design, and reduced total space requirements. The principal disadvantage is storing at least one back-up spare actuator of each size used on the lock.

5.2.2.5 Spillway Gate Power Unit. Spillway gate power unit design should be a function of the maximum normal operating requirements of the dam. A centralized system may be adequate where only one or two gates need to be moved in a single operation, and the length of piping is manageable. A local system, with each power unit serving several gates, can be used for situations such as hydraulic operated wicket gates. Dedicated systems would be the most practical solution for large dams with many simultaneous operations or remote control capabilities.

5.2.3 Hydraulic Components - General. Hydraulic system components are generally specified by parameters of flow rate, pressure rating and optional features. Pressure and flow volume are intimately related with temperature and viscosity of the hydraulic fluid. The system design operating pressure can be best determined by requirements for reliability, efficiency, safety, maintainability and life cycle cost analysis. The system flow rating is generally based upon the required gate operating times. Gate operating times should be computed on the basis of established experience and safety considerations.

5.2.3.1 System Operating Pressure. Design system operating pressures are usually determined by balancing the requirements of the hydraulic pump, the hydraulic actuator design, the piping friction, the control valve ratings and the potential for shock loading. Typical operating pressures for centralized power units are 14 MPa (2,000 psi) or less. Typical operating pressures for local, dedicated, or integral power units are 21 MPa (3,000 psi) or less. Many modern piston pumps are easily capable of trouble free operation up to 34.5 MPa (5,000 psi) for the volumes needed for lock and spillway service. Increased system pressure, however, increases the risk of leakage and the size of some transmission components. Increased size translates to increased life cycle costs. Bending and/or buckling loads will often govern when sizing the cylinders (bore and rod diameter), which sometimes reduces the required operating pressure.

5.2.3.2 System Component Ratings. The manufacturer's published pressure, volume, friction, and fluid compatibility ratings should be used for selection of all system components. Components should be specified to have a normal minimum pressure rating equal to at least twice the maximum normal operating design pressure. Components should be specified to deliver the maximum design volume flow rate at a cumulative pressure loss of less than 1 MPa (150 psi), including main system valves, piping, hose, filters, and manifolds.

5.2.4 Hydraulic Cylinders - General. Hydraulic cylinders convert fluid power into linear motion. There are three basic types of hydraulic cylinders that are used in typical lock and dam machinery applications: the tie rod type, the telescoping type, and the mill type.

5.2.4.1 Cylinder Features. All hydraulic cylinders should be provided with SAE four-bolt flange connections for the supply ports at the top or side of each end. All cylinders should be furnished with air bleeds and oil drains, at the high and low points, respectively, at each end. All cylinders should be provided with "zero-leakage" sealing systems to prevent drift and environmental contamination. All piston rods should be coated with a ceramic material, or chromium plating, over the appropriate steel or stainless steel material. All cylinder mounting features, including trunnions, should be attached by the manufacturer at the factory. The cylinder stroke should be designed with sufficient overtravel to facilitate installation tolerances for proper adjustment. The cylinder rod should be designed with a minimum factor of safety of 3.0 to resist a buckling load under compression.

5.2.4.2 Optional Cylinder Features. The cylinder may be furnished with local control manifolds mounted directly to the cylinder. Cylinders can be furnished with adjustable cushions to assist in deceleration when approaching the stroke limits. Cylinders can be furnished with stop tube or double pistons to assist in resisting side loading of the piston rod.

5.2.4.3 Tie Rod Cylinders. Tie rod cylinders are commonly used in sizes below ten (10) inch bore. These cylinders are more prone to problems caused by field maintenance than other types of cylinders. They are typically designed for lower overall pressure requirements than the mill type cylinder.

5.2.4.4 Telescoping Cylinders. These cylinders are commonly used in situations, similar to an elevator, where installation space is limited, loading is relatively minor, but the cylinder stroke required is very long. Since each stage of the cylinder must be enclosed within another stage, the available force is limited.

5.2.4.5 Mill Type Cylinders. Mill type cylinders are generally rated for the higher pressures than the other designs. The cylinder heads are generally mounted with bolts or capscrews. Most main operating systems should be designed for this type of cylinder.

5.2.4.6 Packaging for Storage and Handling. All cylinders shall be packaged for the maximum storage time and conditions anticipated under the contract duration, including shipping conditions. Cylinders should be shipped with the piston rod(s) retracted and restrained from movement. Cylinder packaging should include provisions for rotating horizontally stored cylinders every 30 calendar days. Cylinders, filled with hydraulic fluid for storage, should be equipped with accumulators, or similar expansion devices, to accommodate oil expansion due to temperature changes.

5.2.5 Hydraulic Motors - General. Hydraulic motors convert fluid power into rotary motion. Pressurized fluid from the hydraulic pump turns the motor output shaft by pushing on the gears, pistons or vanes of the hydraulic motor. Hydraulic motors can be used for direct drive, where sufficient torque capacity is available, or through gear reductions. Most hydraulic motors must operate under reversible rotation and braking conditions. Motors are often required to operate at relatively low speed and high pressure. Motors can experience wide variations in temperature and speed in normal operation.

5.2.5.1 Gear Motors. Gear motors are compact, basic in design, provide continuous service at rated power levels with moderate efficiency, and are highly reliable with high dirt tolerance. There are several variations of the gear motor, including the gerotor, differential gear motor, and roller-gerotor, which produce higher torque with less friction loss.

5.2.5.2 Piston Motors. The most common type of motor available is the axial piston. Axial piston motors have high volumetric efficiency, which permits steady speed under variable torque or fluid viscosity conditions. This permits the smoothest, most adaptable approach to variable loading conditions. Axial piston motors are available in two types of design, swash plate and bent axis. The swash plate design is the most commonly available hydraulic motor. The bent axis design is the most reliable, and the most expensive. Radial piston motors are extremely reliable, highly efficient and rated for relatively high torque. Radial piston motors are less commonly available, which may require extensive investigation into availability to insure adequate procurement competition is possible. All piston motors are available in fixed and variable volume versions.

5.2.5.3 Vane Motors. Vane motors are compact, simple in design, reliable, and have good overall efficiency at rated conditions. Vane motors use springs or fluid pressure to extend the vanes. Vane motors, generally, use a two or four port configuration. Four port motors generate twice the torque at approximately half of the speed of two port motors.

5.2.6 Hydraulic Pumps - General. Hydraulic pumps convert electrical energy into fluid power. The fluid power is in the form of hydraulic fluid delivered to operating devices at a pressure and volume required to perform the work of the system. Gears, vanes or pistons are used to compress the hydraulic fluid to the conditions required by the system. Hydraulic pumps, generally, operate at higher speeds and pressures than hydraulic motors without significant thermal shock, speed and load variations. While some systems use reversible pumps, most lock operating systems currently use a uni-directional pump with a directional control valve to reverse the operation of the actuators.

5.2.6.1 Gear Pumps. The gear pump is a simple, rugged, positive displacement design with a large capacity for a small size. Gear pumps have a high tolerance for fluid contamination, good overall efficiency, and are relatively quiet. While these pumps are fixed volume at a given rpm, their flowrate/rpm characteristics are linear within their efficiency range. Speed and direction control of an actuator can therefore be provided by driving a reversible gear pump with a variable speed electric motor, which makes them ideal for integral type power units. Gear pumps are commonly used for pilot pressure applications. Gear pumps are generally restricted to less than 24 MPa (3,500 psi) service.

5.2.6.2 Piston Pumps. The piston pump is the type most often recommended as the main pressure pump for hydraulic power systems. It has the highest volumetric efficiency, highest overall efficiency, highest output pressures, and longest life expectancy. This type of pump is available in variable displacement models with a large variety of control systems for pressure and capacity. It is recommended that the drive motor speed be designed for 900 to 1,200 rpm, if possible, in order to reduce noise and increase pump life. Piston pumps are generally restricted to less than 42 MPa (6,000 psi) service.

5.2.6.2.1 Axial Piston Pumps. Axial piston pumps are used for high pressure and high volume applications. The two basic types of axial piston pump are the swash plate and the bent axis designs. The bent axis design is considered to be a higher quality pump with less noise, vibration and wear than the swash plate design. Swash plate pumps can be designed to drive a separate pilot pressure pump from a shaft extension, while bent axis pumps will require a separate electric motor/pump arrangement for pilot pressure.

5.2.6.2.2 Radial Piston Pumps. Radial rolling piston pumps are an extremely reliable, simple design. A typical design includes solenoid controls for up to 5 discreet operating speeds. Each of the operating speeds has a variable adjustment range from zero to full volume capacity to permit field adaptation to operating conditions. The typical pumping system includes an integral pilot pump, internal pressure relief valves, and associated control devices for speed of shifting between pumping rates.

5.2.6.3 Vane Pumps. Variable volume vane pumps are efficient and durable, as long as a very clean hydraulic system is maintained. In a very simple circuit the pressure compensation feature of the vane pump reduces the need for relief valves, unloading valves or bypass valves. Vane pumps are generally restricted to less than 14 MPa (2,000 psi) service.

5.2.7 Control Valves - General. Various types of valves are used to control pressure, volume and direction of fluid flow in a hydraulic circuit. Typical operating elements of these valves are poppets, sliding spools, springs, stems, and metering rods. Valves can be controlled manually (i.e.: hand wheel, lever, joystick, etc.), mechanically (cam, roller, toggle, etc.), hydraulically (pilot pressure), or electrically (Linear Variable Differential Transformer, solenoid, etc.). Control valves are used in two basic types of hydraulic circuits, closed loop and open loop.

5.2.7.1 Closed Loop Circuits. Closed loop circuits use a feedback system, which generates input and output electrical signals to track system performance. The electronics compare the input and output signals on a continuous basis in order to automatically adjust the system to the level of performance required. Typical closed loop system valves are servo-valves and proportional valves.

5.2.7.2 Open Loop Circuits. Open loop circuits rely upon the performance characteristics of the individual valve components to meet the system requirements. Basic pressure control valves, flow control valves, and directional control valves are used to alter the pressure, flow, and direction of the fluid power using only simple electrical solenoids for control in an open loop circuit.

5.2.7.3 Proportional Valves. These valves can assume any position between their minimum and maximum settings in proportion to the magnitude of an electrical input signal. They can control direction, flow rate and pressure. Since they are infinitely positionable, the directional valve spools can be designed to throttle the flow rate in each direction of motion. Actuator force or torque can be controlled by varying the pressure. Pressure is often a function of actuator speed in lock and dam operating equipment. Where pressure cannot be related to actuator speed, pressure control valves must be used in the circuit. Proportional valves are mass produced with interchangeable spools and valve bodies. This can lead to slight misalignment, which results in center position “overlap”, or no flow to the outlet ports. This flow “deadband”, while not a problem in flow control type circuits, can cause errors, and instability, in closed loop feedback positioning circuits.

5.2.7.4 Servo-Valves. Servo-valves are made to closer tolerances than proportional valves. These valves have superior response, repeatability, and threshold response. They are, however, considerably more expensive than proportional valves. Repeatability is a measure of the number of times a valve can produce the same flow rate with repeated signals of the same magnitude. Threshold response is the smallest variance in input signal that produces a corresponding change in the flow rate. Meticulous construction is required to produce precise alignment of the spool lands with the valve body ports. The higher cost of servo-valves is usually justified when more sophisticated performance such as high load stiffness, good stability, precise positioning, good velocity and acceleration control, good damping, and predictable dynamic response, is required.

5.2.7.5 Pressure Control Valves. Pressure control valves are used in hydraulic systems to control power and to determine pressure levels at which various operations or actions can occur. Pressure control valves can limit the maximum pressure in a circuit, reduce pressure levels from one part of the circuit to another, provide alternate flow paths for fluid at selected pressure levels, provide resistance to fluid flow at selected pressure levels, and modulate transient pressure shock in a hydraulic circuit. Pressure control valves include pressure relief valves, sequence valves, counterbalance valves, holding valves, unloading valves, reducing valves and shock suppressors. All of these valves have some method of pressure setting adjustment. Valves operating in enclosed areas should be furnished with key-locked handles to discourage casual adjustment. Valves exposed to weather, such as in grated pits, may be furnished with lock nuts to maintain final settings.

5.2.7.5.1 Pressure Relief Valves. A pressure relief valve limits upstream pressure to a preset value by returning part, or all, when sized correctly, of the fluid flow to the reservoir until the upstream pressure drops below the relief setting. The two principle types of pressure relief valves are the spool type and the poppet type. The poppet type has the shorter response time, but the spool type has more stability and accuracy of operation and adjustment. Most main pressure relief and pilot relief valves should be the balanced piston type (spool type) with an appropriate adjustable pressure range. Pressure relief valves should be furnished for the main pressure pump, pilot pressure pump, and each actuator line between the directional valve and actuator inlet ports.

5.2.7.5.2 Sequence Valves. Sequence valves direct flow to a circuit in a predetermined logical sequence by sensing that adequate pressure has been developed in one circuit before allowing flow in another circuit. Sequence valves may have to actuate two or more spools or poppets to connect primary and secondary passages. Sequence valves are generally used in circuits where one actuator must complete its operation before another actuator, at a higher pressure, can begin its operation.

5.2.7.5.3 Counterbalance Valves. A counterbalance valve is a normally closed pressure control similar to a relief valve, but it has a reverse free-flow check valve. Counterbalance valves are used to control an overrunning or overhauling load. They are commonly used on culvert valve control circuits to prevent the open valve from drifting downward when main pump pressure has been blocked by the directional control valve. Counterbalance valves can be used with an internal pilot or a remote pilot actuation. Using a remote pilot can significantly reduce the power required to lower the load at a controlled rate.

5.2.7.5.4 Holding Valves. A holding valve is basically a special type of counterbalance valve, and are functionally similar to a pilot-operated check valve. Pilot-operated check valves trap fluid to prevent actuator movement, but during actuator travel produces little resistance. Counterbalance valves, in addition to preventing movement, add resistance during travel, which increases the power required to operate. Holding valves avoid the objectionable features of both the counterbalance and pilot-operated check. Holding valves also provide built-in thermal-relief protection.

5.2.7.5.5 Unloading Valves. The straight unloader and the differential unloader are two basic types of unloading valves. The straight unloading valve is a two-stage relief valve with its pilot port connected externally to a separate signal source. The differential unloading valve operates on an area differential between the control poppet seat and a pilot piston of 10 to 20 percent. Unloading pressure is controlled by the spring force on the control poppet. The pilot piston is actuated by external pilot pressure such that it unseats the poppet at a preselected pressure. When the poppet opens, the main valve spool shifts to the open position. The pilot piston then prevents the poppet from reseating until the pressure drops below the required differential.

5.2.7.5.6 Reducing Valves. A reducing valve is a normally open valve, which modulates, or blocks, flow at a preset pressure. They control downstream pressure by restricting flow due to the positioning of the spool with respect to the outlet port.

5.2.7.5.7 Shock Suppressors. Sometimes called safety valves, shock suppressors are two-way-valves that “snap” open to relieve hydraulic shock. Hydraulic shock is simply an excessive pressure instantaneously applied to the circuit. When high pressure, high flow rate events occur, the two-way-valve “snaps” open to allow the fluid to pass from the inlet to tank. The small amount of fluid bypassed decreases the rate of pressure rise, thus preventing the shock.

5.2.7.6 Flow Control Valves. Flow control valves are used to control the rate of fluid flow from one part of the hydraulic system to another part. These valves can be used to:

- Limit the maximum speed of the actuating devices,
- Limit the maximum power available to sub-circuits,
- Proportionally divide or regulate the flow to different branches of a circuit, and
- Control the speed of pilot controlled valves.

Flow control valves operate in three general configurations, meter-in, meter-out, and bleed-off. Meter-in and meter-out methods use a throttling approach to restrict the size of the fluid path, while bleed-off bypasses the flow to tank or a lower pressure area of the circuit. Flow control valves can be compensated or non-compensated. Compensated valves automatically adjust to provide uniform pressure drop across the valve to furnish constant flow rates.

5.2.7.6.1 Meter-In Circuits. Meter-in flow controls should be used when the load may “kick back”, the circuit power or pressure level must be retained when the actuator pressure level falls off, and for dividing flows to multiple branch circuits.

5.2.7.6.2 Meter-Out Circuits. Meter-out flow controls should be used when the load is overhauling or overrunning, the load can decrease causing lunging, and when a back pressure is desired for rigidity in motion.

5.2.7.6.3 Bleed-Off Circuits. Bleed-off flow controls should be used when a soft circuit is desired, and when the power to be controlled is a fraction of the circuit power to the actuator.

5.2.7.7 Directional Control Valves. Directional control valves, by providing a choice of flow paths, do one or more of the following:

- Control direction of actuator motion,
- Select alternate circuits, and
- Perform circuit logic functions.

The check valve is the simplest of all directional controls. Other directional controls are described by the number of primary ports available for control. They are usually referred to as two-way, three-way or four-way valves.

5.2.7.7.1 Check Valves. Check valves can be used for a wide variety of functions in a circuit. They can be used to prevent flow in one direction, while permitting free flow or pilot-controlled flow in the other direction. They can be externally piloted to provide an actuator locking function. They can be used in pilot lines to provide rapid release of a pilot-operated spool.

5.2.7.7.2 Two-Way Directional Valves. Two-way valves are generally used to perform logic functions such as AND, OR, and AND/OR decisions. These valves allow flow in one position and no flow in the other position. These valves can be in the normally open or the normally closed position until actuated by levers, solenoids, pilot pressure, etc. Two-way valves can be used to perform interlock or safety functions.

5.2.7.7.3 Three-Way Directional Valves. Three-way valves have a pressure supply port, a tank port, and one actuator port. These valves are generally used with an actuator designed with springs or other means of returning to a rest position, since they can address only one actuator inlet port. This type of valve is not generally recommended for normal lock and dam machinery design, since it is important to use pump flow to control operation in both directions of travel.

5.2.7.7.4 Four-Way Directional Valves. The typical system directional valve for lock and dam projects is the four-way, three position, directional valve. This valve has four main ports; main pressure, tank, actuator A, and actuator B. This permits the valve to reverse actuator direction in a controlled manner with the main pump flow. These valves can be furnished with a wide variety of spools for controlling flow. The directional control valve is usually the single greatest pressure loss point in a hydraulic circuit, therefore it is customary to design this valve for 1.5 to 2.0 times the maximum system flow rate in order to minimize system losses.

Spools. The typical spool used for modern lock and dam hydraulic systems is the blocked center, solenoid-controlled, pilot-operated, spring centered type spool. This type of spool is used successfully in hydraulic systems, which can be remotely operated with a series of interlocks to prevent conflicting machinery behavior. A solenoid operated pilot pressure four-way valve applies pilot pressure to shift the pilot-operated spool in the main pressure four-way valve. The pilot pressure to each side of the spool is usually passed through a combination flow control-reverse free flow check valve to permit adjustment of main pressure spool actuation speed. The spring-centered feature is used in the pilot valve and the main pressure valve to return the system to blocked center when the solenoids are <u>not</u> energized to permit machinery operation. The tandem center type spool has been used with some success, when proper pressure control valves are included in the circuit to prevent actuator drift after main pressure pump shut down.

Controls. Solenoid-controlled, pilot operators are usually used on the more modern open loop type systems to allow remote, or centralized, operation with appropriate electrical or electronic interlocks. Direct solenoid operated valves are generally available in smaller flow rate capacities. All solenoids should be equipped with manual operating pins for troubleshooting and emergency operation. Lever, or other manual, type operators should only be used on the most basic systems, or where human observation of the operation from the local controls is essential.

Mounting Systems. Directional control valves should be mounted on steel manifolds with the associated pressure control valves. Manifold systems are economical, reduce leakage, minimize piping fabrication costs, and reduce space requirements. Aluminum manifolds should not be used with steel piping or steel bolted SAE flange connections due to the localized yielding of the aluminum threads under installation, shock and vibration. The specification should ask for detailed drawings of the drilled passages of the steel manifolds. A manifold, properly prepared for long term storage, of each different type, should be included in the spare parts.

5.2.8 Reservoirs. Hydraulic fluid reservoirs should have a minimum capacity of approximately three (3) times the maximum main pressure pump output capacity. Maximum capacity will be determined by other factors such as the number and size of actuators served, long lengths of large diameter delivery piping or excessive thermal expansion. Since the typical hydraulic cylinder has substantially more fluid per length of stroke on the cap end side than on the rod end side (the rod takes up volume as it retracts into the cylinder), more fluid will be returned to tank when a cylinder is retracted. Where multiple hydraulic cylinders are served, an analysis of all potential operating cases (number of cylinders that can be extended or retracted at the same time) should be performed to determine the maximum and minimum reservoir levels required for the complete system. After the initial reservoir size is determined, its heat dissipation capacity should be checked to determine if it is adequately sized to dissipate heat generated by the individual components of the system and any ambient or solar heat gain. The reservoir should have sufficient capacity to provide a flooded pump suction, without vortex formation, under all operating conditions. The reservoir should be fabricated from annealed and pickled steel or stainless steel plate, designed for the loads applied by all accessories and pumping equipment. Coating the interior of the reservoirs not made of stainless steel with an epoxy system is no longer recommended by many hydraulic system manufacturers. The reservoir should be internally reinforced, as required, with vertical baffles to separate the return oil from the pump suction. The baffles shall be designed to prevent turbulence at the pump suction. The pumps and motors should be mounted with vibration isolators and connected with flexible hoses and conduit, to prevent noise and vibration transmission to the reservoir and fluid. The reservoir should be provided with appropriate oil level gauges, low and high level shutoff switches, magnetic particle collector, drain valves, removable clean-out plates for suction and return sides, suction filters (if required for pumping unit design), and reservoir heaters (if required by the hydraulic fluid design). Separate reservoirs and sealed reservoirs are two basic types of reservoirs that should be considered.

5.2.8.1 Oil level gauges. Oil level gauges should be one, or more, sight gauges placed to show the full normal operating range of fluid levels within the middle 80 percent of the gauge range. The lowest sight gauge installed shall have a thermometer, designed for the maximum normal hydraulic fluid operating range.

5.2.8.2 Shutoff Switches. Float-type shutoff switches have proven to be reliable. Switches can be provided to prevent low suction level, and overfill, as well as issue alarms when approaching fault conditions.

5.2.8.3 Magnetic Particle Collectors. These devices are permanent magnets immersed in the hydraulic fluid which collect metal particles that can cause pump damage. Periodic inspection, and cleaning, of these devices can be essential in the early identification of pump wear problems.

5.2.8.4 Drain Valves and Cleanouts. Reservoir drain valves should be designed to permit easy access for draining the hydraulic fluid to the bottom of the reservoir. This includes placing the location well above the surrounding floor level sufficient to place a disposal container of modest size for collection of the fluid. Cleanouts should be properly sealed, bolted or clamped, and placed for easy access when in service.

5.2.8.5 Reservoir Heaters. Reservoir heat is not required for most installations. There are a large number of viscosity stable hydraulic fluids, designed for aircraft and missile service, which are usable with piston pumps at temperatures down to –40°C (–40°F). Where it is determined to be necessary, the reservoir heating elements should not exceed a watt density of 1.5 watts per square cm (10 watts per square in) of element in order to eliminate “charring” of the fluid.

5.2.8.6 Breathers. Hydraulic systems usually use a replaceable filter-breather device which permits atmospheric air to be drawn into the reservoir. These devices can be furnished with a desiccant type filter for moisture control. Recent experience indicates the best method of breather protection for hydraulic systems in the damp, lock and dam environment is the use of a bladder-type breather system. Where sufficient space is available, the flexible bladder-type breather system seals the hydraulic system against dirt, water, and other contaminants.

5.2.8.7 Control Valve Manifolds. It is beneficial to mount any control valves associated with the pumping system on a control manifold mounted on the reservoir for convenience of adjustment and maintenance. In some cases the directional control valves, pressure controls and flow controls can be mounted on the reservoir to conserve space.

5.2.8.8 Separate Type Reservoirs. Separate reservoirs are the most common design in industrial, or lock and dam, applications. A separate reservoir can be designed for a single pump/motor group serving one or more actuators or multiple pump/motor groups serving many actuators. Some dual chamber locks with centralized power units have one reservoir supplying three pump groups (two of the three are normally used), which operate all of the actuators for both chambers. The three principle versions of separate reservoirs are rectangular, “L”-shaped, and vertical.

5.2.8.8.1 Rectangular Reservoirs. These types of reservoirs use a rectangular steel box to hold the fluid and house the accessories. They can be designed with the pump groups mounted on top, underneath, or inside the reservoir. With top mounting a short suction line is required for each pump which extends below the minimum suction submergence of the fluid. With

underneath mounting the pump groups are provided with a flooded suction which improves pump operating conditions significantly. With inside mounting the pumps are submerged in the fluid and the drive motors are mounted vertically on top of the reservoir.

5.2.8.8.2 "L"- Shaped Reservoirs. "L" – shaped reservoir packages have the pump groups mounted next to the reservoir on a common base. This arrangement provides good access to components for maintenance and repair.

5.2.8.8.3 Vertical Reservoirs. Vertical reservoirs have the pump group in a vertical plane with the pump below a removable reservoir cover. While this arrangement is very compact with a low suction lift requirement, the size is limited by the requirement for lifting the entire pump group, controls and reservoir cover to service any equipment.

5.2.8.9 Sealed Reservoirs. Sealed reservoirs are primarily used for the integral power unit of a self-contained actuator, which consists of a power unit attached directly to the hydraulic cylinder it operates. These actuators can be configured in many different ways by changing the shape of the reservoir and where/how it is attached to the cylinder. The direct connected miter gate actuators recently installed on several locks have long slender reservoirs, made from square structural tubing, bolted to brackets on the side of the cylinder. Tainter valve actuators have also been designed with shorter reservoirs made from round structural tubing and permanently welded to the rear of the cylinder tube during fabrication. This arrangement allows the actuators to fit existing recesses without modification. Sealed reservoirs have a pump mounted inside and submersible motor mounted outside. Since these reservoirs do not have breathers or accumulators, the air pressure inside will vary with cylinder rod position and oil temperature. The actuator should be designed so the normal pressure range in the reservoir is between 21 kPa and 69 kPa (3 and10 psig). Care should be taken to make sure the pressure never goes below atmospheric or above 207 kPa (30 psig).

5.2.8.10 Secondary Containment. Some method of secondary containment for the contents of the fluid reservoir should be provided to eliminate spills and waterway contamination. The reservoir can be specified as "double-walled" with leak detection electronics between the walls. The reservoir can be contained within a containment pit similar to aboveground fuel tanks with leak detection electronics within the pit. This is required for any reservoir with direct drainage features to the waterway, such as floor drains, sump pumps or lock wall recesses. Oil/water separators may be used to treat drainage prior to discharge into the waterway, but these devices should be thoroughly tested prior to installation to insure that the effluent meets all state and local environmental pollution criteria.

5.2.9 Manifolds. Pre-drilled steel manifold blocks have proven to be extremely reliable for connection of control valve assemblies in hydraulic systems. Manifolds provide short, direct flow paths between controls, which reduces friction and response time. Subplate mounted type control valves can be directly mounted, or stack mounted, to the manifold, which eliminates excess piping and fittings. This mounting arrangement reduces leakage. Maintenance costs are reduced by eliminating piping connections. Manifolds can be sensitive to filtration problems, but proper preventative maintenance should yield excellent results. It is essential to specify that

all manifolds should be furnished with re-manufacturing drawings that document the dimensions and locations of all pre-drilled passages, including where fabricating passages have been plugged.

5.2.10 Filters. Pressure-side and return-side filters should be provide on all hydraulic power units. "Spin-on" pressure line filters, rated for full maximum discharge pressure of the pump, should be furnished for the main supply and pilot supply pumps. A large, multiple cartridge, return line filter should be mounted adjacent to the reservoir. Return line filters should be the full-flow type, designed to pass all flow through the filtering elements. Return line filters should, however, include a bypass relief valve system designed to shunt flow around the filter after a pre-set pressure drop is exceeded. Return line filters should be provided with a maintenance indicator which clearly shows when the cartridges need to be replaced. All filters should be rated for a minimum10 micron particulate filtration with a B_{10} filtration ratio of 4.0 in accord with ANSI B93.30M. The system must be designed such that all hydraulic fluid passes through one or more of these filters during installation, testing and normal operation. A 200-mesh suction strainer should be used on hydraulic pump inlets only when required by the pump manufacturer.

5.2.11 Accumulators. Accumulators store hydraulic energy in a manner similar to electric storage batteries. They store potential energy by accumulating pressurized hydraulic fluid in a vessel for later release into the system. Accumulators can improve energy efficiency, absorb shocks, damp pulsation, reduce noise, prevent pump cavitation, compensate for leakage or thermal expansion, and provide emergency operation capability. Accumulators are nominally designated by their energy storage mode, either pneumatic, spring loaded, or weight loaded.

5.2.11.1 Pneumatic Accumulators. Pneumatic accumulators use compressed inert gas, such as nitrogen, to force hydraulic fluid back into the hydraulic system. Compressed air is not used due to the danger of explosive air-oil vapor. Accumulators should be the separated type, which use bladders, diaphragms, or pistons, to separate the hydraulic fluid from the compressed gas. Bladder designs are the most versatile.

5.2.11.2 Spring Loaded Accumulators. These accumulators use a spring compressed by a piston to force fluid into a hydraulic circuit. They are typically used in applications below 3.5 MPa (500 psi).

5.2.11.3 Weight Loaded Accumulators. These accumulators use a heavy weight to push the piston downward, forcing fluid into the circuit. They are typically very large with installation and maintenance problems, and, therefore, not recommended.

5.2.12 Piping. All piping, including tubing and flexible hose assemblies, should be designed for a factor of safety of eight (8), based upon the maximum normal operating pressure. This should provide adequate design tolerance for shock and vibration. Proper design of hose assemblies should include adequate length, swivels, end connections and outer coverings to account for exposure to the environment, equipment movement and adjacent hazards. Black steel pipe should be furnished in the pickled and oiled condition. Stainless steel pipe has,

however, been found to be economically justifiable on a life cycle cost basis with reduced maintenance and leakage due to corrosion. Hydraulic tubing can be used for diameters below approximately 40 mm (1-1/2 in). Hydraulic tube fittings should be swaged-type or flare type. Bite-type tube fittings should not be used. All pipe hangers should be furnished with phenolic shock-absorbing inserts to accommodate hydraulic system shock and vibration.

5.2.12.1 Required Design Features. All piping systems shall have air bleed valves at the high points in the system. All piping systems shall have drain valves at low points in the system. An analysis should be performed to locate shutoff valves in the piping system at sufficient intervals to permit localized drainage of piping for pipeline repairs. Gauge, and pressure transducer, connections should be furnished at appropriate locations for future system troubleshooting. Piping shall be tested to the maximum normal working pressure rating of the pipe, tubing or hose in the system.

5.2.12.2 Fluid Velocity Requirements. Main pressure lines should be designed for a velocity of 3 to 4.5 meter per second (10 to 15 feet per second). Hydraulic return lines should be designed for a velocity no greater than 3 meter per second (10 feet per second). Pump suction lines should be designed for a velocity of 0.6 to 1.5 meter per second (2 to 5 feet per second). Pilot and drain lines should be designed for a velocity of 3 to 4.5 meter per second (10 to 15 feet per second).

5.2.12.3 Piping Layout. The piping system should be arranged to permit convenient removal of all valves, pumps, filters, actuators and associated appurtenances. Shutoff valves should be place around equipment which may need to be removed from the circuit for service. Piping should be sloped slightly to encourage complete drainage during servicing. Expansion and contraction should be considered in any design with long pipelines, with the inclusion of accumulators and hoses as required.

5.2.12.4 Hydraulic Tubing. Tubing is specified by outside diameter and wall thickness. Commercially available tubing is clean and easy to bend. Tubing provides easier installation and less fittings are required. Stainless steel and carbon steel tubing is available in welded and seamless versions. Some difficulty has been encountered with the application of tube fittings to tubing above 40 mm (1-1/2 in) outside diameter.

5.2.12.5 Hydraulic Hose. Hydraulic hose should be used to connect hydraulic components where relative motion, or thermal expansion, must be accommodated. Hose is specified by inside diameter and type of construction. Hose has three basic parts: the tube is the inner liner that carries the fluid, the reinforcement is the part that covers the inner liner with woven, braided, wrapped or spirally-wound materials for strength, and the cover is the exterior material that protects against abrasion, chemicals, weather and ultraviolet rays. Hydraulic hose should be specified as indicated in SAE J517. Plastic hose is lighter, smaller, and lower in electrical conductivity than synthetic rubber hose. Plastic hose is inert to most chemical, hydraulic fluids and ozone. Rubber hose is more resilient and flexible.

5.2.12.6 Piping Fittings. Most piping system leaks occur at fittings or the connection of fittings with valves, pumps, manifolds or actuators. Leaks are generally caused by shock, vibration, thermal expansion/contraction or human impact at joints. Piping fittings should match the type of pipe system in use, such as butt-welded, socket welded, swaged or flare tube, and swaged or crimped hose. Swivel fittings should be used with hydraulic hose to avoid crimping and adverse bending. "Quick" disconnect couplers, which incorporate check valves to shut off flow, can be used for infrequent or emergency connection of equipment to the hydraulic system.

5.2.13 Hydraulic Fluid. Hydraulic fluid is generally selected for compatibility with the main hydraulic pumping unit. The operating range of the pump is the primary consideration for system performance. Most normal operating systems, which experience widely variable temperature and climate conditions, require the use of a petroleum based fluid with a high viscosity index (VI). The permissible viscosity range does vary with different manufacturers and types of pumps.

5.2.14 Gauges. All systems should have properly sized pressure and temperature gauges at locations near important system operating equipment such as the pumps, pressure control valves, actuators and directional control valves. Pressure gauges should be rated for the maximum operating pressure of the system. Gauges with smaller scale ranges have, in general, higher accuracy. Manual pressure gauges should have minimum intermediate graduations of 0.35 MPa (50 psi). Pressure gauges are essential for proper troubleshooting of system performance. All pressure gauges should be provided with pressure snubbers, to protect against shock. Shutoff valves should be used to isolate the gauges until readings are required. Glycerine filled pressure gauges are not required, unless severe vibration is expected at the gauge location.

5.2.15 Special Design Considerations.

5.2.15.1 Limiting System Pressure. In general, pressure relief valves should be provided to insure that pressures cannot exceed 125 percent of pressure during normal operation. In practice, this is accomplished by adjusting by adjusting the relief valve operating pressure to be barely high enough so the gate can be raised or the valve opened.

5.2.15.2 Cylinder Tubes and Rods. Guide specifications indicate cylinder tubes should be ASTM A 519 Grade 1018 heavy wall seamless tubing. However, cylinder tubes fabricated from one piece AISI 4340 steel with one piece ASTM A36 steel trunnions have given satisfactory service for hinged crest gates. Leakage of hydraulic fluid from cylinders. The most common problem occurring with hydraulic cylinders has the leakage of hydraulic fluid. This is generally caused by corrosion and scoring of piston rods. For this reason the material and finish on the piston rods must be matched to the conditions in which the cylinder will be used. Various piston rod coatings have been developed for resistance to corrosion and abrasions. Guide specifications indicate piston rods should be ASTM A 564 or ASTM A 705, Type 630 or XM-12, heat treated to a condition of H-1150 and hard-chrome plated or ceramic coated. However, piston rods fabricated from ASTM A 108, grade 1045, cold drawn, with ceramic coating have also shown indications that they will provide a long life for lock and dam applications. With ceramic coating it is important that the rods are fabricated by a firm that has experience and proven success applying ceramic coatings. In any case, the coating should be in accordance with the manufacturer's recommendations, and the manufacturer should be completely responsible for the

selection of surface preparation of the rod, the chrome plating or ceramic coating process, the quality of the chrome plating or ceramic coating, and the bonding of the coating to the base metal and the finish.

5.2.15.3 Pistons. Pistons should be precision fitted to the cylinder body bore. They should be fine-grained cast iron and should be designed and equipped with seals and bearing rings as

needed, and fabricated from materials as recommended by the Contractor to provide zero leakage. The design should protect the piston rings from blow-out and oversqueezing.

5.2.15.4 Seals. Dynamic seals should be suitable for both frequent and infrequent operation and should be capable of not less than 500,000 cycles of operation in properly maintained systems. Cylinder tubes should also have the bore honed to a surface finish compatible with the seals being used so as to result in zero leakage past the seals.   All seals should be of material suitable for use with the hydraulic fluid specified.

5.2.15.5 Guarantees. Although an exception to DOD policy, designers of some installations have specified guarantee periods greater than one year. In some cases the guarantee period for hydraulic cylinder parts other than the rods have been specified as two years from date of acceptance, and the hydraulic cylinder piston rod’s guarantee period has been specified as five years from date of acceptance. The warranty should be against defective materials, design, chrome plating or ceramic coating of the rod, and workmanship.

5.2.15.6 Design/Build. When advantageous providing the hydraulic system by means of a design/build supply contract should be considered. The design should be based upon the conditions under which they will operate, and hydraulic cylinders are typically used in exterior locations and may be exposed to hot or cold, humid, moist, and/or dusty conditions. Therefore, the conditions in which the cylinders are to be located should be specified in the contract.

5.2.15.7 Spare Cylinders/Parts.   Spare hydraulic cylinders are not recommended for gates actuated by direct connected hydraulic cylinders, unless they can be properly stored and maintained in accordance with the cylinder manufacturers recommendations for long term storage. Synthetic materials for cylinder bearings and seals have greatly reduced the seal problems (compression and drying out) associated with long-term horizontal storage of large cylinders. However, most manufacturers still recommend that stored cylinders should be protected from the elements and fitted with stand pipes to insure they are completely filled with oil. Provisions for periodically exercising stored cylinders is also recommended. Spares should be considered for other hydraulic system components such as control and relief valves, hydraulic pump and motor, etc.

5.2.15.8 Piping. Piping should be pitched a minimum of 1/2 in. per 50 ft in order to provide high and low points, and accumulator tanks should be used in systems with long lines to minimize the effect of hydraulic surge.

5.3 Lubrication. The designer should review the guidance provided in EM 1110-2-1424 for the proper selection of oils, greases and fluids.

5.4 Fire Protection.

5.4.1 Hydraulic Systems. The need for fire protection for hydraulic systems will vary depending on the location of the various parts of the system and the hydraulic fluid used. Options may need to be considered for fire protection such as: providing a sprinkler, spray or fog water system for the hydraulic system, locating a portion of the system to a fire resistant room, or using a fire resistant hydraulic fluid. However, as a minimum NFPA and Building Code regulations must be followed.

5.4.2 EM 1110-2-2608 establishes fire protection guidelines for navigation locks.

5.5 Ice and Debris Control.

5.5.1 Gate Heater. REMR Bulletin Vol.12, No. 2, May 1995 reports on radiant heaters installed at lock and dam projects in the Rock Island District and in St Paul District. Design and installation details are provided for roller gate application. The results of the heater installation were reported as successful.

5.5.2 High Volume Bubbler Systems. This information is taken from a presentation given at the 1998 Heartland Technology Transfer Conference. Additional technical information available to designers considering installing high volume bubbler systems are EM1110-8-1(FR), REMR Bulletin Vol.12, No. 2, May 1995, and the Cold Regions Technical Digest, No. 83-1. These documents provide valuable guidance in designing high volume bubbler systems and the theories involved with using air to melt ice. High volume bubbler systems provide lock personnel a means to control debris and ice formation and ice movement. Controlling the formation and movement of brash ice improves the efficiency of lockages. The benefits obtained by this increase in efficiency are:

- Fewer lock personnel are required to assist with the lockage. This allows more time for lock personnel to be available for other duties.

- Less physical work from lock personnel is required to "push" ice with long pick poles. This promotes a safer working environment for the employees and higher morale among the workers.

- The time required to perform a lockage during winter ice conditions can be reduced.

- Controlling ice against the lock gates reduces gate operating machinery wear and tear. Stresses imposed upon the gate structural members are lower. Machinery and structural components life and time between periods of major maintenance are extended.

- Adhesion of ice to the lock structure and gates can be minimized by the melting action associated with the use of high volume bubblers. Ice of varying thickness can be melted in areas contacted by the released air bubbles.

5.5.2.1 Installation. For existing locks, the installation of high volume bubbler systems should be included as part of lock and dam major maintenance contracts. This allows the installation of the submerged pipe and accessories while the lock is dewatered. This reduces the

overall cost to install submerged high volume bubbler piping. Sufficient time needs to be provided to install the piping for the gate recess flushing screens and main chamber screen at both sets of gates. The landwall compressor and piping can be installed both as part of the major maintenance contracts and in separate contracts that included the same type of work at multiple sites.

5.5.2.2 System Component/selection. The major components of high volume air systems are modeled from the research and design calculations conducted by the Cold Regions Research & Engineering Laboratory. The findings of the research laboratory are from a prototype installation at Starved Rock and Peoria Lock. This research should form the basis of design for high volume air systems to control ice at locks. The components of the high volume system described below are particular to systems installed on the Mississippi River.

5.5.2.2.1 Compressor. The compressors are 150 HP electric motor driven positive displacement rotary screw type. Each compressor is capable of delivering 1275 cubic meter per hour (750 cfm) of free air at 690 kPa (100 psig) full flow and is designed for continuous operation. One compressor serves each bubbler system. The compressor delivers flow to the upstream and downstream gates. Compressor sizing is determined by an iterative air system analysis. The air system analysis determines air discharge rates from orifices in the piping assuming a dead-end pressure. A computer program (Bub-300) developed by the Cold Regions Research & Engineering Laboratory is capable of making this simulation to achieve a one-percent difference between the calculated and specified compressor outputs.

5.5.2.2.2 Supply Pipes. Supply pipes have traditionally been three-inch schedule 40 galvanized steel piping. The piping is routed from a centrally located compressor to each end of the lock chamber. Valve manifolds are installed near the gate recesses to control the delivery of air to each submerged flushing screen. The control valves have typically been three-inch butterfly valves with manual control. Electric control valves were installed at Starved Rock Lock and are well liked by the operators.

5.5.2.2.3 Flushing Screen Pipes. The submerged piping is schedule 40 galvanized steel and varies in size from 76 mm (3 in) to 32 mm (1 1/4 in). The varying size is dependent upon the flushing screen being served and the proximity to the dead-end of pipe. The chamber screen is maintained at 76 mm (3 in.) due to the volume of air being delivered and the distance across the lock chamber. This screen is 29 meter (96 ft) long for a 33.5 meter (110 ft) wide chamber and is designed with 2.4 meter (8 ft) orifice spacing. Gate recess screens are supplied with 76 mm (3 in) piping and reduced accordingly to meet the requirements established by the Cold Regions Research & Engineering Laboratory. The gate recess screens have varying orifice spacing to provide more air near the quoin end of the gate. The orifice spacing follows the recommendations of EM 1110-8-1(FR). Nine orifices are installed along each gate recess-flushing screen.

5.5.2.2.4 Orifices. Drilled pipe plugs provide the desired quantity of air to the water. The pipe plugs are installed in vertical tee fittings along the horizontal pipe runs. 9.5 mm (3/8 in) diameter holes have been determined to deliver the desired quantity of air from the prototype

installations. A design flow of 51 cubic meter per hour (30 cfm) per orifice is desired.

5.5.2.2.5 Check Valves. Freeze protection of the airlines near the water's surface requires the installation of spring loaded check valves. The check valves are installed near the bottom of the lock chamber in each vertical leg of the air supply piping. Check valves have had limited success and are subject to periodic maintenance by divers.

5.5.2.3 Lessons Learned.

5.5.2.3.1 The following lessons learned are based on seven high volume bubbler systems installed within Rock Island District over the last 15 years.

- Specify low ambient temperature compressor enclosures to permit operation in ambient air temperatures as low as -29EC (-20EF).

- Specify compressor lubricant to be food grade polyalphaolefin and environmentally friendly.

- Size back-up generators to accommodate both the electrical load from the lock and dam and the electrical load of the compressor.

- Check valves within the vertical piping have not been 100 percent reliable and freezing in the pipes has been experienced. It may be better to install isolation valves, cross fittings and pipe plugs to allow lock personnel to either charge the vertical piping with air or fill them with environmental RV anti-freeze. Charging the piping with air forces the static water level below the freezing surface and is the preferred method.

- Ball valves or positional butterfly valves with 90 degree full open to full close operation are best suited to deliver the air to the bubbler screens. These valves are preferred over gate valves by lock personnel.

- Ultra violet protection is required for all exposed compressor controls to prevent deterioration.

- When zebra mussel infestation is a problem increased periodic operation should be employed to flush the juvenile mussels from the orifices before they are allowed to reach adulthood. More permanent remediation measures should be incorporated, as they become known. One potential, yet untried, solution would be to incorporate elastomeric pinch valves over the orifices to prevent zebra mussel and sediment intrusion.

5.5.2.3.2 The following lessons learned are based on high volume bubbler systems installed within Pittsburgh District.

- A quoin flusher does a good job of clearing floating debris before a miter gate is opened, while consuming much less air than a gate recess screen. These flushers consist of a single orifice located near the pintle of each miter gate. Each flusher is supplied by a smaller 19 mm (0.75 in.) line and is solenoid operated from the control station. Standard procedure is to operate the quoin flushers briefly each time the gates are opened. The gate recess screens are still needed for ice and heavy debris.

- Bubbler systems were installed on two identical locks with the exact same arrangement except for the orientation of the orifices. The orifices for one system were installed pointing up, while the orifices for the other system were installed pointing down. This was done to see if the response time of these systems could be improved. Each system had quoin flushers and flushing screens for the miter gate recesses, upper bulkhead seal, and upstream approach. As expected, the system with the orifices pointing down had a significantly faster response time (time required for all orifices in a screen to begin bubbling). Orifices installed pointing up allow all of the air remaining in the screen piping after it is shut off to escape. As a result, the pipes are full of water the next time the screen is needed. It takes time for the incoming air to displace the water in the piping thru the orifices. The orifice closest to the supply line starts bubbling first and each successive orifice follows until the last one in the screen begins to bubble. Orifices installed pointing down trap the air remaining in the screen piping after the screen is turned off. The trapped air substantially reduces the amount of water in the pipes the next time the screen is needed. As a result, the orifices in the screen begin bubbling sooner with many starting at about the same time. Once all of the orifices in a screen were bubbling fully, there was no observable difference in the bubbling action between the two systems.

5.6 <u>Safety</u>. Cylinder operated gate hoists present some special concerns. Personnel working on hydraulic systems would normally be mechanics who would be aware of most of the potential dangers, but three items will be discussed. First, oil or gases compressed at high pressures present serious dangers. Gases store enough energy to hurl objects at high velocities. Hydraulic fluids at high pressures can cut or otherwise inflict serious or lethal injuries. Before working on any portions of hydraulic systems they must be de-pressurized. Second, verify that dogging devices are locked before de-pressurizing hydraulic systems or before personnel enter areas under hydraulic operated gates. Procedures must be established for engaging dogging devices, locking out actuation controls, and posting necessary signs for protection of personnel. Third, all personnel who work on the hydraulic systems should be trained in regards to safety as it applies to that equipment.

5.7 Corrosion Protection.

5.7.1 General. Corrosion protection is a combination of the proper selection of materials and selecting the proper coating system for the application. In some instances it may also include the use of cathodic protection systems. Cathodic protection systems are normally more suitable to the gates than to the gate operating equipment. The designer should become familiar with the guidance provided in the CERL technical report "Material Selection Guide for Mechanical Components Used in Civil Works Projects" for the proper selection of materials and EM 1110-2-3400 and UFGS-09965A for the proper selection of coating systems.

5.7.2 Hydraulic Systems. The design of systems for gates actuated by direct connected hydraulic cylinders must consider the environment. Material selection must be based on the corrosively of the water and atmosphere. Cylinders, which are normally in a damp area, should be bead blasted and painted with epoxy paint system. Rods, which are normally under water, should be of stainless steel or of ceramic coated carbon steel and be given cathodic protection. Means must be provided so that the system is always under pressure to prevent water from entering the hydraulic fluid and all piping should be of stainless steel. In addition, heating and/or de-humidification may be required to protect pumps and controls.